



REMR TECHNICAL NOTE CS-ES-4.1

USING CURRENT GUIDANCE TO CONDUCT A STABILITY ANALYSIS OF A CONCRETE GRAVITY STRUCTURE FOUNDED ON ROCK OR SOIL

PURPOSE: To provide a listing of the Corps of Engineers' Engineer Manuals (EMs) and Engineer Technical Letters (ETLs) which contain information and guidance on how to conduct a stability analysis of a concrete gravity structure on a rock or soil foundation; and to provide a general explanation of each EM or ETL listed and its application and limitations in assessing the stability of such a structure.

APPLICATION: A number of parameters are involved in assessing the stability of a concrete gravity structure on a rock or soil foundation. The main parameters are:

- a. Applied and resistive forces.
- b. Calculation procedures to obtain evaluation parameters.
- c. Evaluation criteria which use the evaluation parameters to judge the structure's safety in stability.

All the necessary information concerning the various parameters used in a stability analysis is not contained in any one EM or ETL, and many of the applicable EMs and ETLs were written to provide guidance on the design of particular types of structures. Thus, these EMs and ETLs cover more than just stability, and some of them duplicate information applicable to a stability analysis. Sections of some of the older EMs and ETLs have been superseded by more current issues of other EMs and ETLs, but other sections are still applicable. Thus, while the information and guidance needed to perform a stability analysis are available in these EMs and ETLs, they must be used with the knowledge of what sections provide current Corps guidance. This Technical Note will help to rapidly orient the new or inexperienced engineer to the proper EM or ETL to use for the various parameters and procedures for a structural stability assessment of a concrete gravity structure on a rock or soil foundation.

SCOPE: This Technical Note presents:

- a. A listing of EMs and ETLs which contain information on evaluation of the stability of concrete gravity structures on rock or soil foundations, giving the number, title, and date issued (Table 1).
- b. A listing of the major objectives for a stability analysis and the EMs and ETLs which provide current guidance (Table 2).

- c. A listing of the EMs and ETLs which give applicable stability guidance and criteria that is arranged by civil works structure type (Table 3).
- d. A chronological listing of the EMs and ETLs along with a general description of their contents and pertinent information concerning their use in a stability analysis (under the "DISCUSSION" heading).

Table 1

Applicable EMs and ETLs

ETL 1110-2-303	Earthquake Analysis and Design of Concrete Gravity Dams, Aug 1985
ETL 1110-2-256	Sliding Stability for Concrete Structures, Jun 1981
ETL 1110-2-22	Design of Navigation Lock Gravity Walls, Apr 1967
ETL 1110-2-301	Interim Procedure for Specifying Earthquake Motion, Aug 1983
EM 1110-2-2400	Structural Design of Spillways and Outlet Works, Nov 1964
EM 1110-2-2502	Retaining Walls, May 1961 (Reprinted to include Ch 1-3)
EM 1110-2-2602	Planning and Design of Navigation Lock Walls and Appurtenances, Jun 1960 (Ch 1)
EM 1110-2-3001	Planning and Design of Hydroelectric Power Plant Structures, Dec 1960
EM 1110-2-2607	Navigation Dam Masonry, Jul 1958 (Ch 1)
EM 1110-2-2200	Gravity Dam Design, Sep 1958 (Ch 1-2)
EM 1110-2-4300	Instrumentation for Concrete Structures, Sep 1980
EM 1110-2-2501	Wall Design, Flood Walls, Jan 1948 (Reprinted to include Ch 1-3)
EM 1110-2-3104	Structural Design of Pumping Stations, Jun 1958
EM 1110-1-1804	Geotechnical Investigations, Feb 1984
EM 1110-1-1802	Geophysical Exploration, May 1979
EM 1110-1-2907	Rock Reinforcement, Nov 1979
EM 1110-2-1907	Soil Sampling, Mar 1972
EM 1110-2-1906	Laboratory Soils Testing, Nov 1970 (Ch 1-2) <u>Rock Testing Handbook</u> , Oct 1977

NOTE: Not all the information and guidance presented in these EMs and ETLs are current since sections of some have been superseded; see Table 2 for information on the EM or ETL which contains current guidance for a major objective.

Table 2

EMs and ETLs by Major Stability Analysis Objective

Major Objective of Stability Analysis	Most Recent EM/ETL	Superseded EMs/ETLs	Comments
Criteria and guidance for assessing the seismic resistance of concrete gravity dams	ETL 1110-2-303, Aug 1985	Does not supersede any but applies when any conflict occurs between this and any other EM/ETL.	EM 1110-2-2200 and ER 1110-2-301 give supplementary information.
Criteria and guidance for assessing sliding stability of gravity dams and other concrete structures	ETL 1110-2-256, Jun 1981	Supersedes the sliding stability criteria contained in: ETL 1110-2-22 ETL 1110-2-2400 ETL 1110-2-2602 EM 1110-2-2607 EM 1110-2-2200 Some loading and load case concepts presented in the above EMs and ETL are still applicable.	Initial investigations and testing and sampling procedures are presented in: EM 1110-1-1804 EM 1110-1-1802 EM 1110-2-1906 EM 1110-2-1907 <u>Rock Testing Handbook</u>
Criteria and guidance for assessing the overturning stability of concrete structures on rock foundations	Overturning criteria have not changed, and some information about overturning is presented in most of the EMs/ETLs listed in Table 1. The most complete coverage is presented in ETL 1110-2-22, para 22, section a.	None	No manual exists which gives a presentation of the mode of failure in overturning
Criteria and guidance for determining the applied loads which are to be used for stability analysis of concrete structures on rock foundations	All EMs/ETLs in Table 1 give some information about loadings for stability analysis of concrete structure on rock foundations. EM 1110-2-2200 and EM 1110-2-2502 are fairly complete in their presentation of loadings, but other EMs/ETLs in Table 1 give pertinent information.	None	
Criteria and guidance for improving structural stability	EM 1110-1-2907		

Table 3

EMs and ETLs by Civil Works Structure Types

<u>Type Civil Works Structure</u>	<u>Applicable EMs and ETLs</u>	<u>Comments</u>
Gravity dams	EM 1110-2-2200 EM 1110-2-2607 EM 1110-2-2400 ETL 1110-2-256 ETL 1110-2-303	ETL 1110-2-303 mainly presents guidance for a dynamic stress analysis of concrete gravity dams, but it also presents some information concerning stability analysis for structures subject to earthquake loadings.
Navigation locks	EM 1110-2-2602 EM 1110-2-2501 ETL 1110-2-22 ETL 1110-2-256	
Pumping stations	EM 1110-2-3104 ETL 1110-2-256	
Power plant structures	EM 1110-2-3001 EM 1110-2-303 ETL 1110-2-256 ETL 1110-2-2200	
Spillways and outlet works (includes intake towers)	EM 1110-2-2400 EM 1110-2-2606 EM 1110-2-303 EM 1110-2-2200 EM 1110-2-2502 ETL 1110-2-256	Many times these monoliths are similar to gravity dam, navigational dam, or retaining wall monoliths.
Retaining walls	EM 1110-2-2502 EM 1110-2-2501 EM 1110-2-256	
Floodwalls	EM 1110-2-2501 EM 1110-2-2502 ETL 1110-2-256	

DISCUSSION:

- a. ETL 1110-2-303, Earthquake Analysis and Design of Concrete Gravity Dams, Aug 1985. This ETL is the product of many years of research as to the effects of seismic loading on concrete gravity dams. It presents concepts about stress analysis and also presents some general guidance for using seismic loading in a stability analysis. It presents only a few new considerations which are different from previous EMs and ETLs about stability analysis. It still recommends the seismic coefficient method for stability analysis as presented in EM 1110-2-2200. Exceptions and references to the other EMs and ETLs are as follows:
 1. The seismic coefficient used in the analysis should be no less than that given in ER 1110-2-1806.
 2. The sliding stability analysis should follow ETL 1110-2-256.
 3. The selected pool level for the earthquake loading cases should be according to that recommended in paragraph 7 of ETL 1110-2-303.
- b. ETL 1110-2-256, Sliding Stability of Concrete Structures, Jun 1981. This ETL presents the current criteria and guidance for assessing the sliding stability of gravity dams and other concrete gravity structures. It presents the limit equilibrium method and an alternative method which uses applied and resistance force components along the assumed sliding plane for evaluating the sliding stability of a structure. ETL 1110-2-256 develops the evaluation methods using multiple planes of sliding. It presents some general ideas about handling seepage and uplift pressures. It also gives some information about earthquake analysis, although a more comprehensive development of the seismic coefficient method for using inertia loads and Westergaard's method for considering dynamic water effects is presented in EM 1110-2-2200.

ETL 1110-2-256 defines the factor of safety as the ratio of available shear strength to the shear stress required for equilibrium and applies the safety factor to the material strength parameters. It assumes the potential failures plane with single or multiple wedges, and solves the factor of safety by an iterative procedure using trial values of a safety factor. This procedure is similar to the procedure presented in EM 1110-2-2501 and EM 1110-2-1902. The minimum safety factors are 2.0 for normal static loading conditions and 1.3 when seismic loading is used except for retaining and floodwalls. ETL 1110-2-256 presents many of the limitations of the shear friction method which was previously used by the Corps for assessing sliding stability.

Laboratory testing to obtain parameters for stability evaluations are presented in more detail in Waterways Experiment Station Technical Report GL-83-13, "Design of Gravity Dams on Rock Foundations: Sliding Stability Assessment by Limit Equilibrium and Selection of Shear Strength Parameters," by Glenn A. Nicholson, Oct 1983.

- c. ETL 1110-2-22, Design of Navigation Lock Gravity Walls, Apr 1967. The purpose of this ETL is to provide guidance in determining earth pressures and sliding stability for navigation lock gravity walls. The criteria on overturning and earth pressures are current. The sliding stability criteria are obsolete.
- d. ETL 1110-2-301, Interim Procedure for Specifying Earthquake Motion, Aug 1983. This ETL provides interim guidance on procedures to be used in specifying earthquake motions for design analyses of new civil works structures and in the assessment of existing civil works structures.

Enclosure 2 to this ETL includes a general discussion concerning the circumstances requiring the specification of earthquake motions, the use of "deterministic" and "probabilistic" methods, the sequence of procedures necessary to select the design earthquakes, project site ground motions, and a discussion of the use of response spectra and accelerograms.

- e. EM 1110-2-2400, Structural Design of Spillways and Outlet Works, Nov 1964. This EM describes the loading cases to be used for analyzing the stability of spillway walls and intake towers generally used with embankment type dams.
- f. EM 1110-2-2502, Retaining Walls, May 1961. This EM contains a good general presentation on backfill loads, Coulomb criteria for active and passive pressures, and the effect of surcharge loads. It also gives guidance about the location of resultant backfill loads for various slopes of backfill away from the structure. Some concepts concerning relevant testing which should be used to determine the parameters needed to calculate backfill pressures are discussed. At-rest earth pressures are discussed. The accepted method (Monoabe and Okabe) for obtaining the soil pressure from earthquake loadings is mentioned. The stability criteria in this EM are still current.
- g. EM 1110-2-2602, Planning and Design of Navigation Lock Walls and Appurtenances, Jun 1960. Guidance for the structural planning and design of navigation lock walls and appurtenant facilities for civil works projects is presented. General information about locks and the design of locks is presented in this EM. It also presents the following significant information about stability evaluations:
 - 1. Allowable bearing pressures for rock and the distribution of foundation pressures on rock foundations. A factor of safety of 4.0 for maximum allowable bearing pressures is suggested.
 - 2. General information on loadings such as uplift, gate loads, water pressures, earth pressures, earthquake loads, tow impact, line loads, ice loads, and wind loads is presented.
 - 3. Each monolith must be stable independent of the other monoliths.

4. General concepts about overturning.

The shear friction method presented in this EM is superseded by methods presented in ETL 1110-2-256.

- h. EM 1110-2-3001, Planning and Design of Hydroelectric Power Plant Structures, Dec 1960. Some pertinent information about live and dead loads for analysis, wind loads (20 psf instead of 30 psf), impact loads, and crane loads is contained in this EM. Case loadings are presented. Sliding criteria should be used as presented in ETL 1110-2-256, but this EM should be studied when evaluating the stability of hydroelectric power plants because there are some details which are pertinent to power plants which are not presented elsewhere.
- i. EM 1110-2-2607, Navigation Dam Masonry, Jul 1958. This EM presents the structural design criteria to be used in designing low masonry navigation dams. Design loads, stability requirements, and allowable stresses are discussed. It gives some general criteria for stability evaluations which are still valid. The overturning evaluation of pier and abutment monoliths is valid. The general criteria concerning uplift are valid but are presented in more detail in EM 1110-2-2200. The load due to surcharge of moving water or earth, water loads, surcharge loads, wind loads, ice loads, gate or bulkhead loads, and miscellaneous loads are valid. The earthquake loading has been changed and is presented in ETL 1110-2-303. The information presented about case loadings is general but valid. The concept of a time lag in drawdown is presented in paragraph 19 of EM 1110-2-2607.
- j. EM 1110-2-2200, Gravity Dam Design, Sep 1958. The overturning criteria in this EM are still current. The sliding stability criteria have been superseded by ETL 1110-2-256. Allowable tensile stresses on dam sections are given in this EM. The main concepts which are applicable and presented in EM 1110-2-2200 are:
 - 1. Uplift pressures and drain effects on uplift pressure.
 - 2. The seismic coefficient method for using earthquake forces in the stability analysis. The method is presented clearly in EM 1110-2-2200; however, criteria on the reservoir pool elevation to be used for the earthquake loading case are contained in ETL 1110-2-303 (paragraph 7a), and criteria for the minimum seismic coefficient to be used are contained in ER 1110-2-1806.
 - 3. The Westergaard formula for obtaining the inertia effects of reservoir water loads in the dams.
 - 4. Case loadings information and loadings such as ice pressures, wind pressures, and subatmospheric pressures.
- k. EM 1110-2-4300, Instrumentation for Concrete Structures, Sep 1980. This EM is included because instrumentation is so important to documenting the response of structures and allowing checks on design and analysis procedures.

1. EM 1110-2-2501, Wall Design, Flood Walls, Jan 1948. The purpose of this EM is to formulate and set forth general rules and procedures for the design of floodwalls, including foundation investigations. This EM was well researched and written because much of the discussion on design methods, concepts about design, and criteria is informative and valid even though the EM was written in January 1948. A new manual which presents guidance and criteria for both retaining walls and floodwalls is currently being finalized and will be available soon. This EM has three changes dating up to 1962 and the sliding stability method of analysis has been revised according to ETL 1110-2-256.
- m. EM 1110-2-3104, Structural Design of Pumping Stations, Jun 1958. The purpose of this EM is to list the important structural features common to pumping stations, and to some degree peculiar to them, and to present methods and limitations within which their design should be undertaken.
- n. EM 1110-1-1804, Geotechnical Investigations, Feb 1984. This EM establishes criteria and presents guidance for geotechnical investigations during the various stages of development for civil and military projects. Geotechnical investigations are made to determine those geologic, seismologic, and soils conditions that affect the safety, cost, effectiveness, and design of a proposed engineering project. Insufficient geotechnical investigations, faulty interpretation of results, or failure to portray results in a clearly understandable manner have contributed to costly construction changes and postconstruction remedial work and could be the cause of failure of a structure. The investigations are performed to determine the geologic setting of the project; the geologic, seismologic, and soil conditions that influence selection of the project site; the characteristics of the foundation soils and rocks; all geotechnical conditions which influence project safety, design, and construction; and sources of construction materials.
- o. EM 1110-1-1802, Geophysical Exploration, May 1979. This EM provides guidance and information concerning the use of geophysical exploration methods and equipment in geological and foundation investigations. Geophysical methods are useful adjuncts to subsurface drilling and sampling in geologic and foundation investigations. They are used for two general purposes: (1) the interpretation of geologic profiles, and (2) the determination of material properties for use in design and analysis. This EM includes a main text that is intended to provide sufficient information to evaluate the usefulness of a particular geophysical method or series of techniques in determining specific subsurface characteristics or parameters that can be applied to solving a particular design or construction problem, and also includes appendices that are provided to guide operating personnel in the proper procedure or technique to follow in conducting a specific type of geophysical survey.
- p. EM 1110-1-2907, Rock Reinforcement, Nov 1979. The purpose of this EM is to outline techniques and procedures of rock reinforcement for underground and surface structures in civil engineering works.

The discontinuous nature of rock masses permits many possible modes of deformation. In this respect, the design of rock reinforcement should always emphasize the most probable modes of deformation that may lead to collapse and the placement of reinforcement in such a manner as to guard against collapses. The procedure to be followed in designing a rock reinforcement system should not be restricted to the reinforcement elements only but must also consider and be integrated with the overall structure of the rock mass.

- q. EM 1110-2-1907, Soil Sampling, Mar 1972. This EM presents recommended procedures for obtaining, handling, shipping, and storing undisturbed soil samples to be used to aid in the design of Corps of Engineers civil works projects. Some special field tests are included as appendices. The design of engineering structures requires accurate knowledge of subsurface soil conditions and physical properties of the foundation materials. The most "undisturbed" samples possible are required to determine these properties, demanding extreme care in application of sampling methods. Proper soil sampling is a combination of science and art; many procedures have been standardized, but alteration and adaptation of techniques are often dictated by specific investigation requirements.
- r. EM 1110-2-1906, Laboratory Soils Testing, Nov 1970. This EM presents recommended testing procedures for making determinations of the soil properties to be used in the design of civil works projects. Because of the enormous variety of different types of soils and the problems encountered in applied soil mechanics, testing procedures for determining the shear strengths of soils have not been standardized. It is generally necessary to adapt the testing procedures to the specific requirements of an investigation. The procedures for soils tests described in this EM are considered to represent the best current guidance for obtaining acceptable design data. Nevertheless, tests must be constantly reviewed to ensure that the results have meaning with respect to design. Tests which do not measure clearly defined engineering properties (such as Atterberg limits, specific gravity, grain-size analyses, and compaction), however, do require adherence to standardized procedures. The dangers of injudicious testing must be recognized. As an example, compaction test results must be carefully evaluated if the material coarser than 3/4 in. (or some other size) has been removed according to the standard method.
- s. Rock Testing Handbook (Standards and Recommended Methods), interim standards 1978 (this handbook is continuously being updated). The Rock Testing Handbook is a compilation of standard and recommended rock testing methods and has been prepared for use in both the laboratory and the field.